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DISPOSAL OF POLYMER SOLID WASTES BY PRIMARY POLYMER PRODUCERS AND PLASTICS FABRICATORS

Chester W. Marynowski

Stanford Research Institute

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Disposal of Polymer Solid Wastes by Primary Polymer Producers and Plastics Fabricators

This report (SW-34c) was prepared for
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FOREWORD

Because of the tremendous growth (historical and forecast) in the use of polymers, the disposal of polymer wastes has assumed an increasingly important role in our total waste management effort.

To most of us, the term "polymer wastes" connotes primarily the mass of consumer goods containing polymers, after each of those goods has served its primary function, has become worn out or unfashionable, or has somehow outlived its economic usefulness. This aspect of polymer wastes has an important and well publicized bearing on the litter problem and on the optimum design and operation of community waste disposal systems. Since its inception (with the passage of the Solid Waste Disposal Act of 1965) the Federal solid waste management program has been aware of the importance of this "post-consumer" polymer wastes problem, and has sponsored a continuing program of research projects and demonstration grants devoted to the alleviation of specific facets of the problem.

A less familiar but nonetheless decidedly important aspect of the subject of polymer wastes is that of "pre-consumer" wastes--those generated by the primary producers and processors of polymers, and by the fabricators of polymer products. Such wastes have numerous causes, such as failure to meet product specifications, product spills, and carryover of product into effluent process streams. Some industries generate mainly a clean polymer scrap that can be and often is largely recovered and reprocessed or sold; this material does not enter the waste picture until

it becomes "post-consumer" waste. Other industries generate predominately contaminated polymer wastes that not only yield no return, but represent a significant disposal expense. Still others generate mostly clean wastes, potentially suitable for reprocessing to noncritical specification products but actually not reprocessed or sold to others, because specific economic factors pertinent to each case are unfavorable.

This report deals exclusively with the industrial, or "pre-consumer" part of the polymer solid waste problem. It explores the nature and extent of the problem in the United States for that segment of the plastics industry representing the largest product tonnage; namely, the segment dealing in the production and fabrication of the principal thermoplastics. It presents technical and economic information on polymer waste disposal methods in actual use, and evaluates alternative approaches to polymer solid waste disposal. This information should represent a significant step toward the effective future management of polymer wastes and solid wastes in general.

--SAMUEL HALE, JR.
Deputy Assistant Administrator
for Solid Waste Management

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This report on the present practices of the plastics industry in the disposal of its own polymer solid wastes was prepared by Stanford Research Institute. The statements, findings, and conclusions are those of the Institute and do not necessarily reflect the views of the U.S. Environmental Protection Agency.

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INTRODUCTION

This study had the following specific objectives:

1. To determine the nature and extent of the polymer solid waste problem experienced by major, primary producers of large volume thermoplastic resins in the United States and by a cross section of plastics processors and fabricators.

2. To gather technical and economic information on polymer disposal methods.

3. To make a preliminary technical evaluation of all reasonable approaches to polymer solid waste disposal.

To accomplish these objectives, an extensive data collection program was conducted involving a survey of major producers of polymers and fabricators of plastics (including personal visits to selected plants), and of manufacturers of waste disposal equipment.

The field work was supplemented with a selective search and evaluation of the recent technical literature, including pertinent reports of the Department of Health, Education, and Welfare, the Department of the Interior, and other agencies involved in solid waste management. An extensive bibliography, organized according to principal subject matter, is provided at the end of this report.

The plastics industry already reclaims and recycles much of its reusable polymer scrap, either into the same product line that generates the scrap, or into a less critical product line. (In fact, the industry recognizes various grades of resin, such as "first quality," "technical grade," "off-grade," "scrap," and "waste.") However, as resin prices have fallen in recent years, the scrap market has become much more

selective--most of what used to be salable scrap is now waste that represents a disposal expense.

To avoid possible ambiguity, the definition of polymer solid waste adopted in this study has excluded all scrap that is recycled or sold for use essentially as a polymer. In other words, such reuse is considered to constitute an avoidance of waste rather than a disposal method. It is in the same category as the avoidance of waste by the adoption of new process technology that generates less waste initially. There is no doubt that waste avoidance techniques are extremely important to the overall problem of polymer waste management; however, because of the proprietary nature of the pertinent technological innovations, most companies are not willing to reveal details about them.

It should be noted that this study was concerned with the generation and disposal of waste, not with its in-plant management. Also, the study did not include nonpolymer solid wastes such as general plant trash. The information reported herein is primarily that provided by survey respondents, and is limited to the degree of detail that was furnished to the survey team.

SUMMARY

Production of all thermoplastic and thermosetting resins (SIC Code 28210) in the United States was 16 billion pounds in 1968, of which 12.3 billion pounds (over three-fourths of the total) represented thermoplastics. The statistics for all major resin types are shown in Table 1. The aggregate growth rate of all thermoplastic resins is expected to level out at about 11 percent per year over the next decade, compared to an expected rate of about 5 percent per year for thermosets. Thus, thermoplastics will represent an even greater share of total resin production in the future.

Three types of thermoplastics--polyolefins (PO), polyvinyl chloride (PVC), and polystyrene (PS)--have dominated their recent phenomenal growth, and should continue to do so. Polyolefins include both high- and low-density polyethylene (HDPE and LDPE, often lumped together as PE) and polypropylene (PP). The top position in thermoplastics is unquestionably held by polyethylene resins, whose 1968 production of 4.5 billion pounds was nearly twice that of PVC, about two and a half times that of straight and rubber-modified PS, and about five times that of PP. Table 2 shows the estimated distribution of major U.S. thermoplastics production capacity at the end of 1969.

Based on the present survey, thermoplastic polymer solid wastes are estimated to be generated by the U.S. plastics industry at an average rate of 3.3 percent of resin production, equivalent to an estimated 1969 waste generation of 460 million pounds (Table 3). One-third of the total waste (1.1 percent of production) is contributed by primary resin producers, and two-thirds (2.2 percent of production) by plastics processors and fabricators.

Table 1

PRODUCTION STATISTICS FOR MAJOR RESIN TYPES

	1968 Production	
	Billions of Pounds	Percent of Total Resins
Polyethylene (low density)	3.3	21
Polyethylene (high density)	1.2	7
Polypropylene	0.9	6
Polystyrene (straight and rubber-modified)	1.8	11
Polyvinyl chloride	2.4	15
Cellulosics	0.2	1
Other thermoplastic resins	2.5	16
(Total thermoplastic resins)	(12.3)	(77)
Alkyd	0.6	4
Coumarone-indene	0.3	2
Epoxy	0.2	1
Phenolic	1.1	7
Polyester	0.6	4
Urea and melamine	0.7	4
Other thermosetting resins	0.2	1
(Total thermosetting resins)	(3.7)	(23)
Total resins	16.0	100

Source: U.S. Tariff Commission.

Table 2

DISTRIBUTION OF PRODUCTION CAPACITY
FOR LARGE VOLUME THERMOPLASTIC RESINS

Polymer		U.S. Producers	U.S. Plants	Estimated Capacity, End of 1969 (billion lb/yr)
PO	PE — LDPE	13	21	4.25
	PE — HDPE	13	15	2.11
	PP	8	8	1.26
	PVC	23	35	3.72
	PS	15	30	2.54
				13.88

Table 3

POLYMER SOLID WASTE GENERATION BY U.S. THERMOPLASTICS INDUSTRY

	Estimated 1969 Thermoplastic Resin Production or Processing Rate (billion lb/yr)	Estimated 1969 Thermoplastic Solid Waste Generation Rate		
		Million lb/yr	Percent of Production	Average Tons/Day per Surveyed Plant
Primary resin producers	13.8	153	1.1	7.7
Plastic processors and fabricators	13.8	307	2.2	0.6
Total thermoplastics industry	13.8	460	3.3	--

Individual plants deviated considerably from these estimated average waste generation rates. Polyethylene resin producers reported that polymer wastes ranged from 0.5 to 4.0 percent of resin production, averaging 1.75 percent. Limited data obtained from producers of other resins suggest that they generate proportionately much less polymer waste, probably between 0.4 and 0.8 percent of resin production. For the case of plastics processors and fabricators, the amount of waste is not markedly correlated with the type of thermoplastic resin, but varies considerably as a function of the application (Table 4). Such critical applications as wire and cable insulation have an unreclaimable polymer reject rate generally exceeding 10 percent whereas, at the other extreme, such noncritical items as molded toys, housewares, and decorative articles may have virtually zero nonreclaimable scrap.

Table 4

PROCESSING AND FABRICATION WASTE
AS A FUNCTION OF PRODUCT TYPE

	Reported Waste (Percent of Processed Polymer)		
	Average	Maximum	Minimum
Molding compounds	0.7	1.0	0.5
Film and sheet	1.8	2.0	1.6
Flexible packaging	1.4	3.0	0.5
Rigid containers (incl. foam)	1.2	4.0	0.7
Wire and cable	10.3	25.0	10.0
Pipe, toys, housewares, etc.	0.2	0.3	0.0

The companies surveyed had quite varied estimates of the prospects for change in the amounts of waste generated. A slight majority of each industry group forecast no significant change; however, the minority that did forecast change anticipated a reduction of from 20 to 50 percent of present waste amounts, primarily through improved salvage and reclaim techniques rather than through process changes leading to lower initial waste generation. All industry sources agreed that fluctuations in the price of plastic scrap could have a major effect in drawing the line between scrap and waste.

Polymer waste disposal practices presently employed by the plastics industry were reportedly limited to three: open dumping, sanitary landfill, and incineration. Resin producers (representing relatively concentrated sources of polymer wastes, reportedly ranging from 0.85 to 22.5 tons per day per plant) typically handled their own waste disposal on company land. By contrast, plastics processors and fabricators (representing a much larger number of individual plants, with correspondingly less waste per plant) typically depended on public agencies or private contractors for their waste disposal.

The cost data reported in this survey indicate that the U.S. plastics industry spent about $5.6 million in 1969 to manage its 460 million pounds of thermoplastic polymer solid waste, for an average unit cost of about $24.30 per ton. Resin producers as a group reported an aggregate average unit cost of $26.00 per ton, whereas the corresponding figure for processors and fabricators was $23.50 per ton. However, individual plants reported unit costs deviating widely from the above averages, presumably reflecting correspondingly wide variations in cost accounting practices. The survey data provide no breakdown of the reported unit costs into their components of initial waste collection, in-plant handling, transportation, direct disposal operating costs, and equipment amortization. Consequently, these data do not lend themselves to a reliable comparison of the direct disposal operating costs for the various reported disposal techniques.

For most parts of the United States, sanitary landfill will be the most economical and practical of the "acceptable" disposal methods for polymer solid wastes, at least for the next 10 years. As available landfill sites become more distant from waste sources, the economic advantage will shift to incineration, even though simultaneously the pressures of stricter air pollution regulations will force the use of modern, well supervised, highly automated incineration equipment, provided with efficient effluent gas cleaning accessories. Looking still further into the future, the optimum long term solution to industry's polymer solid waste problem (specifically, that portion of the problem not avoidable through improved in-plant reclaim techniques) will probably be through use of efficient, economical, centralized disposal facilities, each capable of processing all types of waste from many plants in a given area. Such large centralized facilities may find it economic to combine waste disposal with some degree of salvage, as well as with recovery of the fuel value of the waste for steam or power generation.

DESCRIPTION OF THE PLASTICS INDUSTRY

Because of their useful properties, cost advantages, and versatility, plastics constitute one of the fastest growing sectors of the chemical industry. U.S. production of all thermoplastic and thermosetting resins (SIC 28210) was 16 billion pounds in 1968, up from 11.4 billion pounds in 1965 and 6.3 billion pounds in 1960.[1] The value of 1968 resin shipments was $3.9 billion, accounting for nearly 15 percent of the basic chemical industry's sales of $26.4 billion.[2]

The 16-billion pound production in 1968 comprised 12.3 billion pounds of thermoplastics and 3.7 billion pounds of thermosetting resins.[1] For the thermoplastics, the growth rate has averaged 14.6 percent per year for the 1960 to 1968 period, and 12.5 percent per year for the more recent 1965 to 1968 period. These growth rates are more than twice those of the thermosets for the corresponding periods. Present forecasts[2] are for a gradual leveling out of the aggregate growth rates to about 11 percent per year for thermoplastics and about 5 percent per year for thermosetting resins. Thus, thermoplastics are expected to represent an even more dominant share of the total plastics market in the future. Individual resins may of course deviate substantially from these aggregate growth rates.

A. General Structure

The plastics industry is composed of three major sectors, with some overlap:

- The producers of the basic resins

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- The processors who convert the resin into some convenient standard shape or form

- The fabricators who fashion the final product from the resin directly, or from a processed form. (In the latter case, the fabricator is often called a "converter.")

Figure 1 gives a more detailed outline of the organization of the plastics industry.

The resin producer usually begins with the basic raw material (such as petroleum or natural gas), manufactures the monomer, and ends up with the resin. Some producers begin with purchased monomer, while others continue beyond the resin stage into processing and fabrication. The resin producer today characteristically has an operation requiring a large investment, an economic and adequate raw material supply, an advanced technical ability, an extensive research and development program, and an aggressive sales force.

Plastics processors and fabricators concentrate on custom operations (made-to-order parts), proprietary operations (using specially designed or developed toolings), or captive operations (utilizing the fabricated parts in other company functions to make finished products). In the United States alone, there are estimated to be 2500 plastics processors and close to 4000 fabricators. Most of these are relatively small firms specializing in particular resins, fabricated shapes, or finished products. They generally do not have the research facilities or resources to develop new fabrication techniques, and are thus often dependent on the resin producers, who commonly expend considerable effort on applications research.

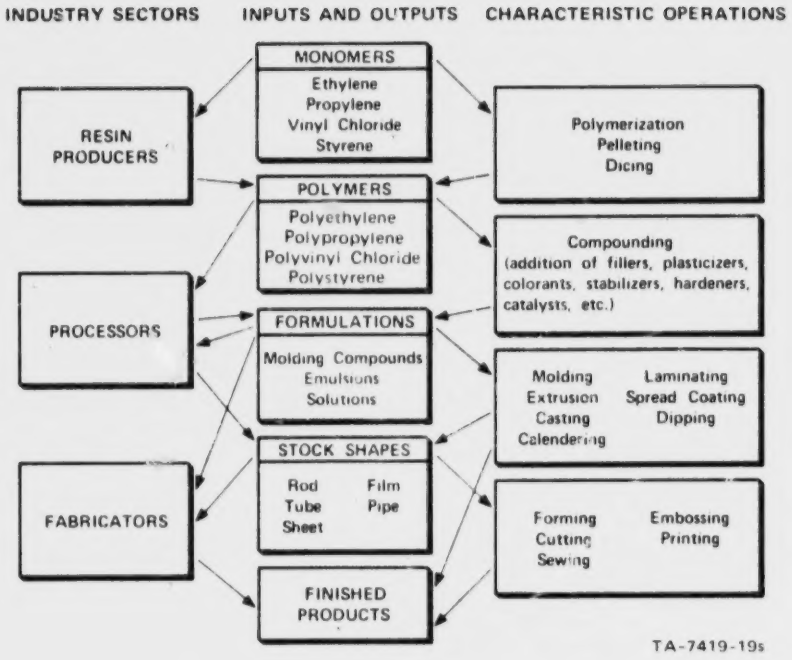


FIGURE 1 STRUCTURE OF PLASTICS INDUSTRY

B. Products and Processes of Resin Producers

Thermoplastic resins have paced the growth of the plastics industry primarily because of their demonstrated ease of fabrication, decreasing monomer prices, new technology, and economies of scale. Three types of thermoplastics--polyolefins (PO), polyvinyl chloride (PVC), and polystyrene (PS)--have dominated this growth, accounting for 60 percent of total 1968 plastics and 78 percent of 1968 thermoplastics.

Industry statistics for polyolefins (SIC 28214) include both high- and low-density polyethylene (HDPE and LDPE, often lumped together as PE), and polypropylene (PP). Polyvinyl chloride, including copolymers containing over 50 percent PVC, accounts for over 80 percent of total vinyl resins (SIC 28212). Polystyrene, including the rubber-modified, high impact copolymers, but not the more expensive styrene-acrylonitrile (SAN) or acrylonitrile-butadiene-styrene (ABS) resins, accounts for about two-thirds of total styrene resins (SIC 28213). The leading resin types are described below in greater detail.

1. Polyethylene (PE). The top position in thermoplastics is unquestionably held by polyethylene resins. Their 1968 production of 4.5 billion pounds was nearly twice that of PVC, about 2-1/2 times that of straight and rubber-modified PS, and about 5 times that of PP.

PE resins contain predominantly the repeating unit $(-CH_2-CH_2-)$. They range from wax-like materials of relatively low molecular weight (10,000 to 25,000) to rigid, tough plastics of ultrahigh molecular weight (2,000,000 to 4,000,000). Most commercial resins have molecular weights in the range of 50,000 to 500,000.

PE resins are usually classified according to two main types: low-density (LDPE), which is usually branched chain, and high-density (HDPE), which is predominantly linear. The two types have different degrees of

crystallinity, and therefore have different values of such physical properties as softening point, low temperature brittleness, flexural stiffness, and tensile strength. They are made by separate processes that differ considerably in polymerization conditions.

a. Low-Density Polyethylene (LDPE). There are 13 U.S. producers of LDPE, operating 21 plants in this country, 16 of which are concentrated in the Gulf Coast area. Table 5 shows the estimated plant capacities at the end of 1969.

In 1968, there were 3.29 billion pounds of LDPE produced in the United States and the estimate for 1969 is 3.70 billion pounds. Total installed capacity at year end is estimated at 4.25 billion pounds, and average operating capacity during 1969 at 4.0 billion pounds. Thus, the 1969 production represents a 93 percent utilization of capacity.

The growth rate for LDPE has been 15 percent per year for the 1960 to 1968 period, and 14 percent per year for the more recent 1965 to 1968 period; it is estimated to average about 12 percent per year over the next five years. The present good supply-demand balance is expected to hold at least into 1972.[3]

Until recently, virtually all LDPE (specific gravity 0.91 to 0.95) was made by one of the high-pressure processes that have evolved since the pioneering research of Imperial Chemical Industries Ltd. in the 1930s. High purity ethylene is polymerized at 10,000 to 30,000 psi in the presence of a catalyst (small amounts of oxygen, oxides of nitrogen, organic peroxides, or other sources of free radicals) in either a stirred autoclave or a tubular reactor (Fig. 2). In general, no solvent is employed. The reactor effluent is flashed and the unreacted monomer is recycled. Molten polymer is extruded in the form of rods or strips, usually under water, and is cut into small pellets or cubes, for marketing.

Table 5

ESTIMATED LDPE CAPACITIES AT END OF 1969

Producer and Location	Capacity (million lb/yr)
Allied Chemical	
Orange, Tex.	25
Chemplex	
Clinton, Ia.	180
Cities Service (Columbian Carbon)	
Lake Charles, La.	70
Dow Chemical	
Freeport, Tex.	300
Placquemine, La.	200
Du Pont	
Orange, Tex.	400
Victoria, Tex.	160
Eastman Kodak	
Longview, Tex.	250
El Paso Natural Gas-Dart Industries	
Odessa, Tex.	300
Enjay Chemical	
Baton Rouge, La.	180
Gulf Oil	
Cedar Bayou, Tex.	220
Orange, Tex.	200
Monsanto (Northern Petrochemical)	
Texas City, Tex.	130
National Distillers (USI Chemicals)	
Deer Park, Tex.	300
Tuscola, Ill.	160
Sinclair-Koppers	
Port Arthur, Tex.	175
Union Carbide	1,000
Torrance, Calif. (100)	
Whiting, Ind. (225)	
Seadrift, Tex. (300)	
Texas City, Tex. (250)	
South Charleston, W. Va. (125)	
TOTAL	4,250

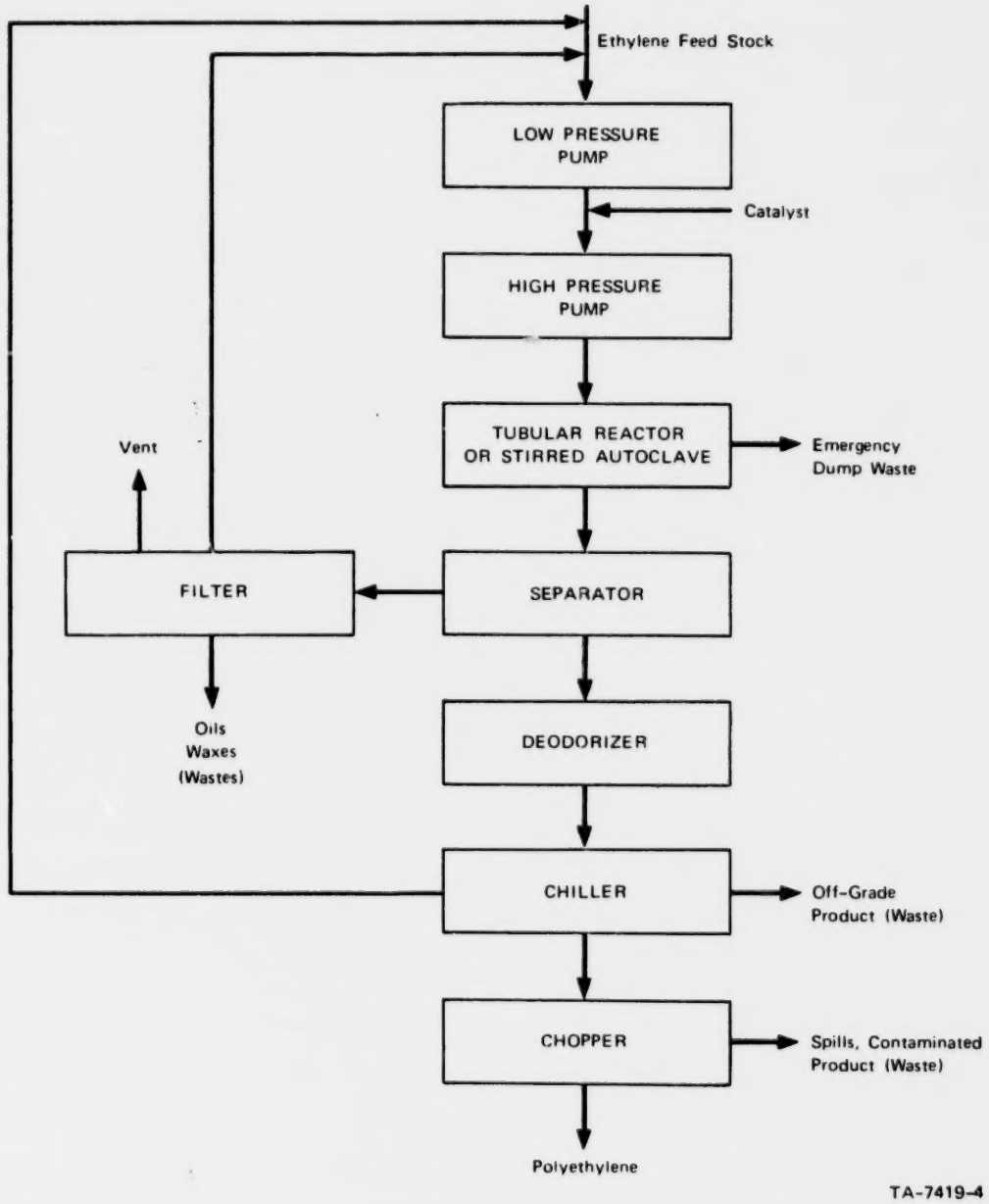


FIGURE 2 HIGH-PRESSURE PROCESS FOR LOW DENSITY POLYETHYLENE PRODUCTION

In April 1969 Phillips Petroleum Company announced development of a low pressure process (500 to 600 psi) for manufacture of LDPE. It is reported to use a catalyst of the same type as that used in the Phillips process for HDPE. The process will go into production at the company's Houston plant. However, nothing has been revealed to date about the potential impact of this process on waste polymer generation.

b. High-Density Polyethylene (HDPE). As in the case of LDPE, the production of HDPE is concentrated in Texas and Louisiana. Table 6 lists the 13 U.S. producers and the estimated capacities of their 15 plants at the end of 1969.

Production of HDPE reached 1.25 billion pounds in 1968, and 1.39 billion pounds is forecast for 1969. This represents an 89 percent utilization of the estimated average 1969 operating capacity of 1.56 billion pounds. Year-end installed capacity is expected to reach 2.11 billion pounds.

The growth rate for HDPE has averaged 24 percent per year from 1960 to 1968, and 17 percent per year for the more recent 1965 to 1968 period; it is expected to average 15 percent per year for the next five years. Even with additional capacity from Amoco, Du Pont, and Monsanto coming onstream in 1970, it is expected that at least 85 percent of HDPE capacity will be used next year.[3]

All HDPE (specific gravity over 0.940) is manufactured in so-called low-pressure processes (operating in some cases as low as 300 psi). Various types of stereospecific catalyst are used, e.g., aluminum alkyls and titanium tetrachloride (Ziegler process, Fig. 3), chromium oxide on silica or silica-alumina (Phillips process, Fig. 4), and molybdena on alumina with various promoters (Standard Oil Co. of Indiana process). The highly oriented (crystalline) polymer is formed either as a solution or in the

Table 6

ESTIMATED HDPE CAPACITIES AT END OF 1969

Producer and Location	Capacity (million lb/yr)
Allied Chemical	
Baton Rouge, La.	200
Orange, Tex.	25
Celanese Corp.	
Deer Park, Tex.	195
Chemplex	
Clinton, Ia.	125
Dow Chemical	
Freeport, Tex.	75
Placquemine, La.	75
Du Pont	
Orange, Tex.	150
Gulf Oil	
Orange, Tex.	100
Hercules	
Parlin, N.J.	100
Monsanto	
Texas City, Tex.	180
National Petrochemicals	
LaPorte, Tex.	170
Phillips Petroleum	
Houston, Tex.	220
Sinclair-Koppers	
Port Arthur, Tex.	80
Union Carbide	
Seadrift, Tex.	250
USI Chemicals	
Deer Park, Tex.	170
TOTAL	2,115

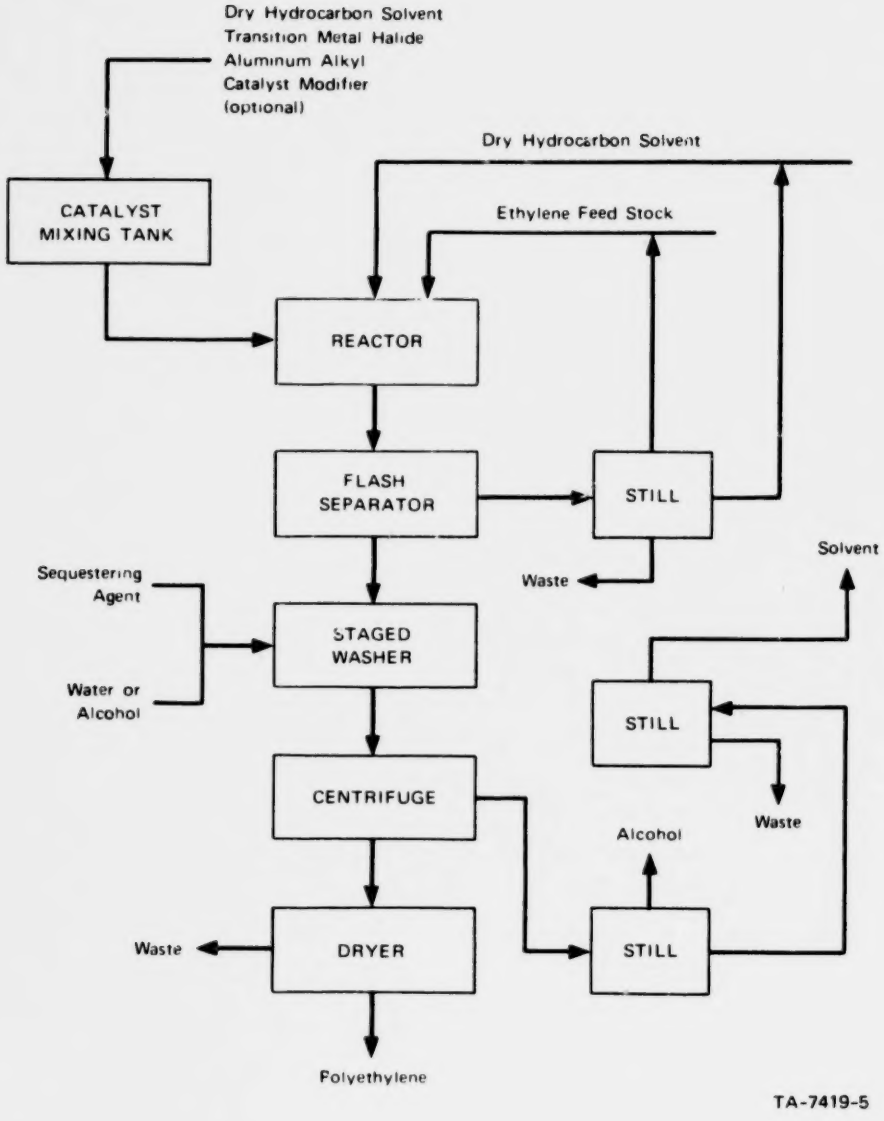


FIGURE 3 ZIEGLER PROCESS FOR HIGH DENSITY POLYETHYLENE PRODUCTION

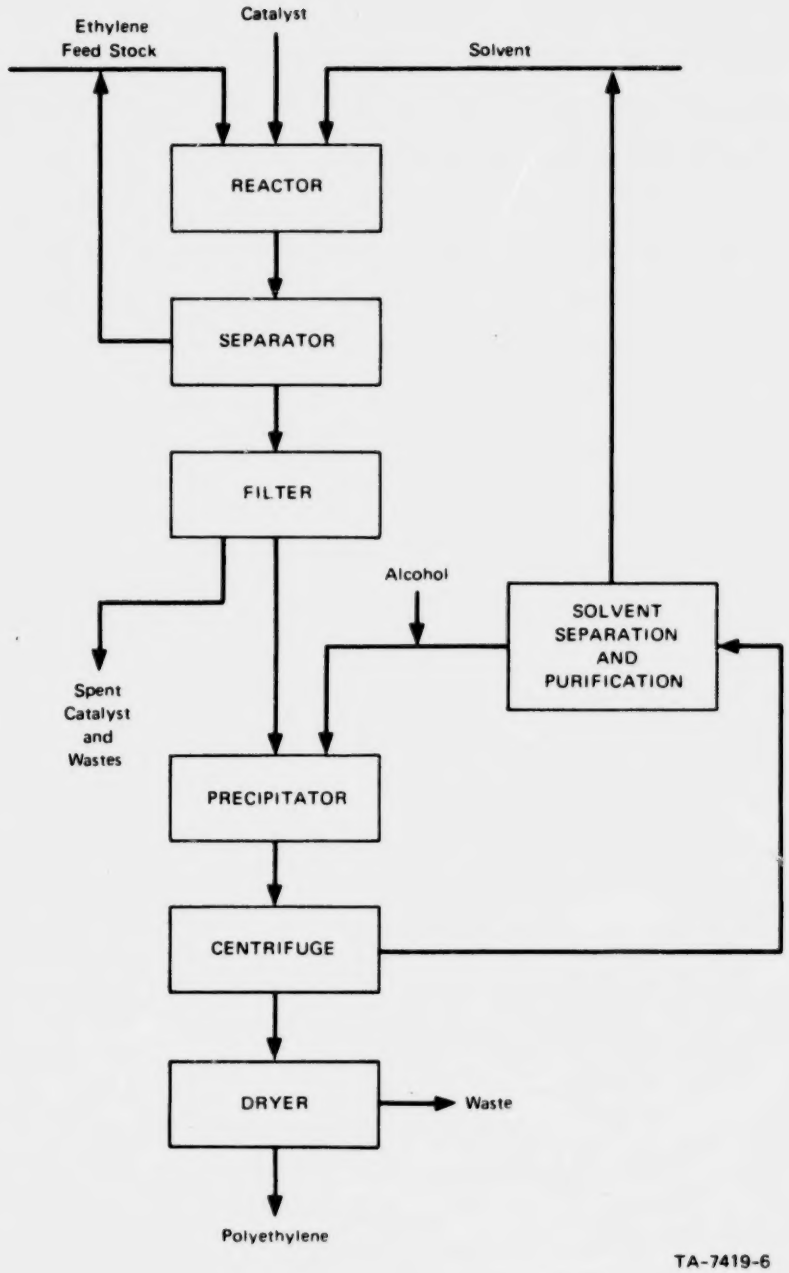


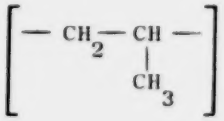
FIGURE 4 PHILLIPS PROCESS FOR HIGH DENSITY POLYETHYLENE PRODUCTION

form of a slurry in a hydrocarbon diluent. In general, unreacted monomer and solvent are removed by flashing, and the catalyst is removed by filtration and extraction. The resulting polymer fluff or crumb is dried and pelleted by extrusion, much like LDPE. About 80 percent of present production is by large plants using the Phillips process.

2. Polypropylene (PP). This member of the polyolefins family is also manufactured mainly in the Gulf Coast area. Table 7 lists the eight U.S. producers and the estimated capacities of their eight plants at the end of 1969.

Production of PP totaled 0.9 billion pounds in 1968, and is expected to reach 1.1 billion pounds in 1969, representing approximately a 92 percent utilization of the average 1969 capacity of 1.2 billion pounds. The growth rate for PP has averaged a phenomenal 46 percent per year from 1960 to 1968, and a still impressive 33 percent per year for the more recent 1965 to 1968 period; it is expected to average 16 percent per year for the next five years. Scheduled additions to plant are expected to result in a temporary oversupply by 1971, when it is estimated that an average of 1.9 billion pounds of capacity will produce only 1.5 billion pounds of resin.[4]

Polypropylene consists predominantly of the following repeating structure:



It is made from high-purity propylene under almost the same conditions as those used for HDPE, except that the stereospecific catalyst system is different. The polymerization step may be either batch or continuous,

Table 7

ESTIMATED PP CAPACITIES AT END OF 1969

Producer and Location	Capacity (million lb/yr)
Alamo Industries (Diamond Shamrock) Houston, Tex.	70
Avisun (Amoco) New Castle, Del.	250
Enjay Chemical Baytown, Tex.	225
Hercules Lake Charles, La.	370
Novamont Kenova, W. Va.	80
Dart/El Paso Natural Gas Odessa, Tex.	50
Shell Chemical Woodbury, N.J.	120
Texas Eastman Longview, Tex.	90
TOTAL	1,255

and both versions are in use. Figure 5 shows the principal steps in a typical continuous process.

3. Polyvinyl Chloride (PVC). There are presently 23 U.S. producers of PVC resins, and 26 of their 35 plants (Table 8) are located in the northeastern part of the country.

The 1968 PVC production of 2.40 billion pounds is expected to grow to 2.66 billion pounds in 1969, representing 89 percent of the estimated average 1969 operating capacity of 3.0 billion pounds. It is likely that the "nameplate" installed capacity figures of Table 8 have been slightly overstated by producers to discourage competition; nevertheless, utilization of capacity is expected to remain at about 90 percent for at least the next two years, because of good demand and an improving monomer supply situation.

The growth rate for PVC averaged 12.4 percent per year from 1960 to 1968, falling off to 9.4 percent per year for the 1965 to 1968 period; it is expected to rebound to an average of 11.5 percent per year for the next five years.[5]

Polyvinyl chloride consists predominantly of the repeating structure $[-CH_2-CHCl-]$. Production is exclusively batchwise. Of the four major polymerization processes available (i.e., suspension, emulsion, solution, or bulk), the suspension process accounts for 85 to 90 percent of total production. It is shown schematically in Fig. 6.

In the suspension method, vinyl chloride monomer is dispersed as small droplets into a stabilized suspending medium consisting of water containing small amounts of proprietary suspending agents. The suspension is then heated in the presence of catalysts (such as organic peroxides). After the desired degree of polymerization, the suspension is stripped free of monomer, is blended with other batches, and is washed,

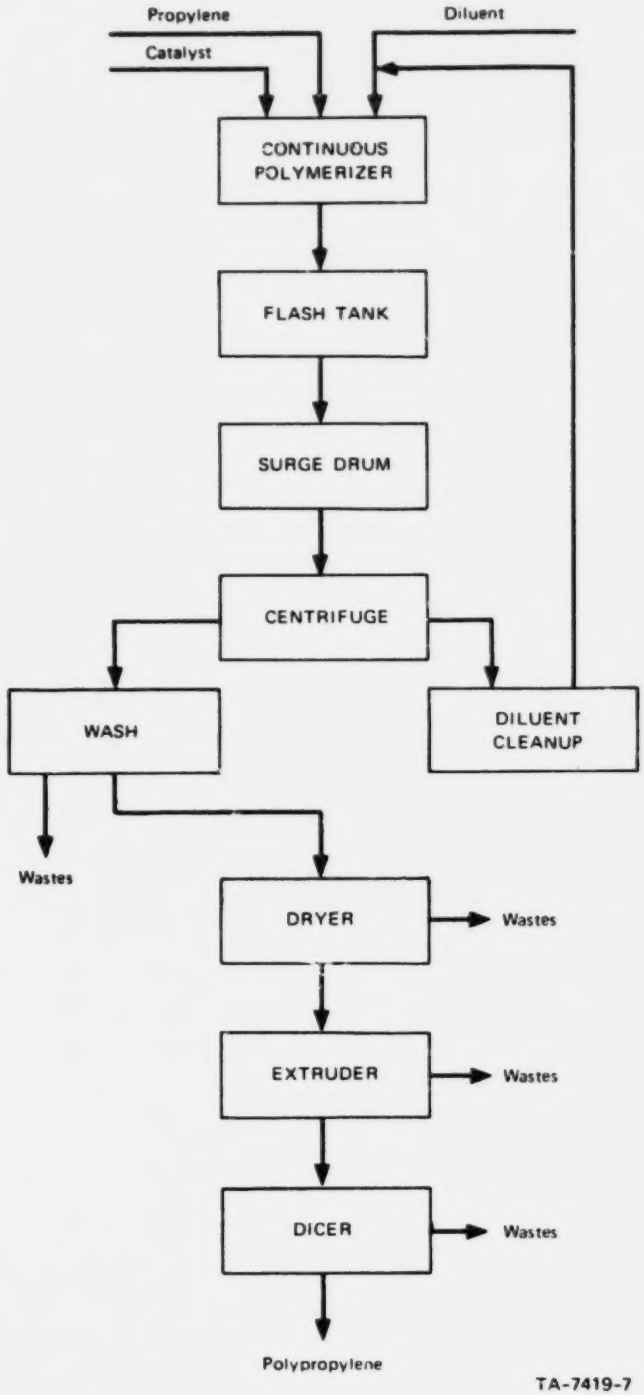


FIGURE 5 CONTINUOUS PROCESS FOR POLYPROPYLENE PRODUCTION

Table 8

ESTIMATED PVC CAPACITIES AT END OF 1969

Producer	Location	Capacity (million lb/yr)
Airco	Calvert City, Ky.	120
Allied Chemical	Painesville, Ohio	200
American Chemical	Long Beach, Calif.	70
Atlantic Tubing	Cranston, R.I.	100
Borden	Illiopolis, Ill.	250
	Leominster, Mass.	
Continental Oil	Aberdeen, Miss.	155
Diamond Shamrock	Deer Park, Tex.	240
	Delaware City, Del.	
Escambia Chemical	Pensacola, Fla.	50
Ethyl Corp.	Baton Rouge, La.	150
Firestone Tire & Rubber	Perryville, Md.	115
	Pottstown, Pa.	125
General Tire & Rubber	Ashtabula, Ohio	75
B. F. Goodrich	Avon Lake, Ohio	630
	Henry, Ill.	
	Long Beach, Calif.	
	Louisville, Ky.	
	Niagara Falls, N.Y.	
	Pedricktown, N.J.	
Goodyear Tire & Rubber	Niagara Falls, N.Y.	80
	Plaquemine, La.	40
Great American Plastics	Fitchburg, Mass.	40
Hooker	Burlington, N.J.	70
Keysor Chemical	Saugus, Calif.	60
Monsanto	Springfield, Mass.	150
Olin	Assonet, Mass.	125
Pantasote	Passaic, N.J.	120
	Pt. Pleasant, W. Va.	
Stauffer	Delaware City, Del.	80
Tenneco	Burlington, N.J.	140
	Flemington, N.J.	75
Union Carbide	Texas City, Tex.	320
	South Charleston, W. Va.	
Uniroyal	Painesville, Ohio	135
	TOTAL	3,715

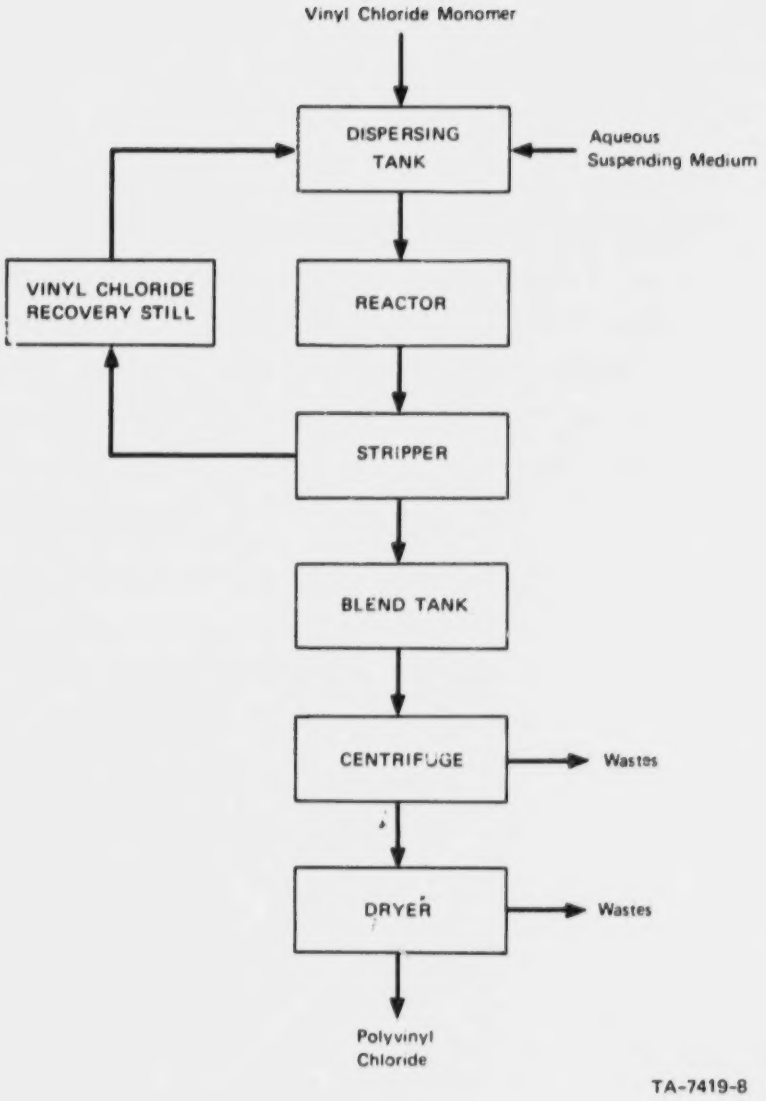


FIGURE 6 SUSPENSION PROCESS FOR POLYVINYL CHLORIDE PRODUCTION

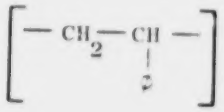
centrifuged, and dried. The effluent stream from the centrifugation step contains the majority of the plant wastes, including significant amounts of very fine polymer.

4. Polystyrene (PS). PS resins are presently made by 15 producers in the United States, with 24 of the total 30 plants (Table 9) located in the northeastern part of the country.

United States production of straight and rubber-modified PS reached 1.79 billion pounds in 1968 and is expected to total 2.1 billion pounds in 1969. This represents a 91 percent utilization of the estimated average 1969 operating capacity of 2.3 billion pounds. Additions to capacity are expected to parallel the production growth rate over the next few years, and consequently operation should remain at about 90 percent of capacity.

The growth rate for PS averaged 13 percent per year from 1960 to 1968, but this included a growth of only 10 percent per year for the 1965 to 1968 period. The near-term outlook is good, and the growth rate should rebound to about 11 percent per year over the next five years.[c]

Polystyrene consists predominantly of the following repeating structure:



where ⌀ represents the aromatic phenyl group, C_6H_5. The bulk polymerization process is believed to account for most commercial production, although the suspension and emulsion polymerization processes are also widely used. One may also use a combination process (such as that of

Table 9

ESTIMATED PS CAPACITIES AT END OF 1969

Producer	Location	Capacity (million lb/yr)
Amoco Chemicals	Leominster, Mass. Medina, Ohio Joliet, Ill. Willow Springs, Ill. Torrance, Calif.	170
BASF	Jamesburg, N.J.	80
Cosden Oil & Chemical	Big Spring, Tex.	145
Dart Industries	Holyoke, Mass. Ludlow, Mass. Joliet, Ill. Santa Ana, Calif.	140
Dow Chemical	Midland, Mich. Allyn's Point, Conn. Hanging Rock, Ohio Torrance, Calif.	700
Foster Grant	Leominster, Mass. Peru, Ill.	190
Hammond Plastics	Oxford, Mass.	25
Howard Industries	Hicksville, N.Y.	15
Monsanto	Springfield, Mass. Addyston, Ohio Long Beach, Calif.	375
Richardson Company	West Haven, Conn.	50
Shell Chemical	Wallingford, Conn. Marietta, Ohio	80
Sinclair-Koppers	Kobuta, Pa.	300
Solar Chemical	Leominster, Mass.	60
Southern Petrochemicals	Houston, Tex.	40
Union Carbide	Bound Brook, N.J. Marietta, Ohio	170
	TOTAL	2,540

Fig. 7) in which bulk polymerization is carried only to a syrupy stage, following which the reaction is taken to completion by suspension polymerization. The finishing operations are generally similar to those used for PVC resins. Most new PS plants are large and are designed for continuous operation.

C. Fabrication Processes for Thermoplastic Resins

Thermoplastic resins are transformed into finished products by the characteristic primary operations shown in Fig. 1 (Summary), and described below. In some cases, two or more separate steps may be involved.

Injection Molding. Heat-softened resin is forced under high pressure into a mold of desired shape; upon cooling, the article is removed. Articles of complex shape, such as toys, furniture, and closures are formed in this manner.

Blow Molding. Heat-softened resin in the form of a tube or blob is placed within a suitable mold and forced by air pressure to take the shape of the mold; the article is removed upon cooling. Bottles, carboys, and other hollow articles are produced this way.

Powder Molding. Finely divided resin is poured into a suitable heated mold, where the resin fuses to the mold surface and builds up a wall that may, upon cooling, be stripped from the mold. Large items such as boats, barrels, and milk cans are conveniently made by this process.

Extrusion. Heat-softened resin is forced continuously under pressure through a die to form a film, sheet, tube, rod, filament, or other article having a uniform cross section throughout its length. Simultaneous inflation of extruded tubing, called "blow extrusion," is a popular method for

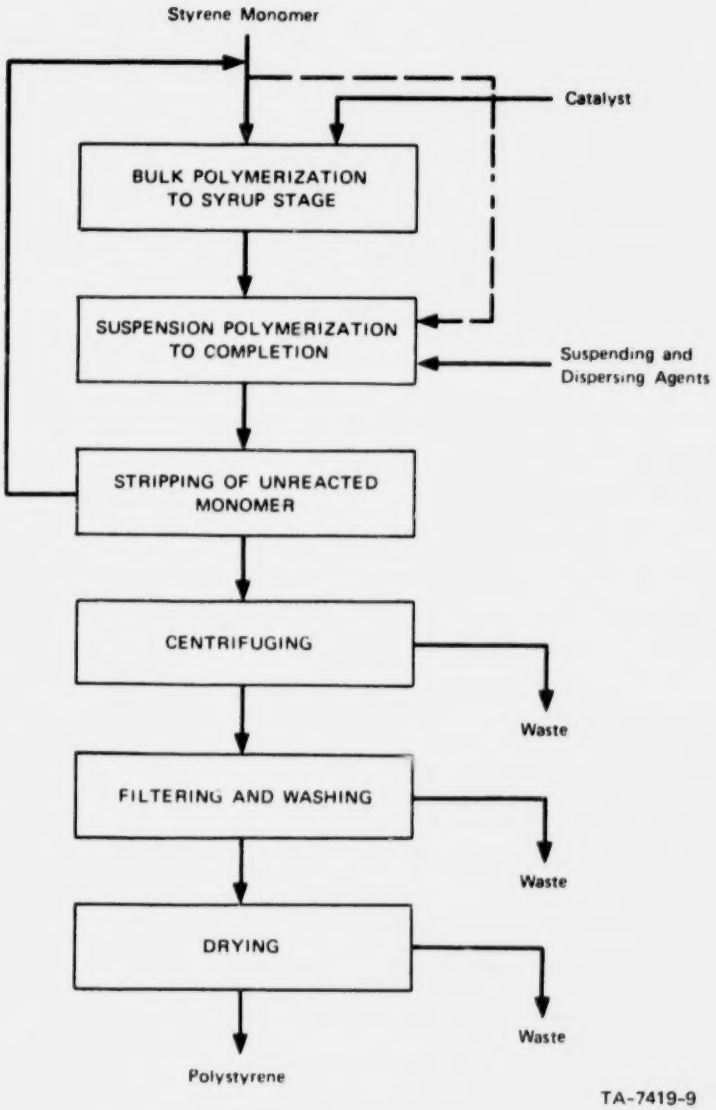


FIGURE 7 BULK-PLUS-SUSPENSION PROCESS FOR POLYSTYRENE PRODUCTION

production of oriented thin film. Wire and cable are plastic coated simply by being moved through the die within the plastic being extruded.

Calendering. Heat-softened resin is passed between revolving rollers to form a continuous length of sheeting or film. If desired, the film may almost simultaneously be laminated with a substrate of paper, fabric, or other material by passing the two layers between rollers.

Coating. Permanent coatings may be applied to a surface by a variety of methods in addition to those covered above. Heat-softened resin may be spread uniformly on flat surfaces by a blade; irregular surfaces may be coated by either dipping or spraying the heated object with finely divided resin.

Secondary operations of fabrication are frequently carried out upon some intermediate product forms, such as film, sheet, or rod, to convert them into end products.

Thermoforming is probably the most important secondary operation. Heat-softened sheet, film or foamed sheet, is forced against a mold, to form items such as boxes, cups, and trays. Other secondary operations include machining, cutting, sewing, sealing, embossing, and printing.

Because each of the major thermoplastic resins has a unique spectrum of properties, each of them also has a similarly unique spectrum of markets, as shown in Table 10. Nearly half of all LDPE is used for film and sheet, whereas this use accounts for only a small part of the market for the other resins. HDPE is the dominant blow molding resin. Injection molding is the largest market for PS and PP; PP also finds a major market in fibers and filaments. The markets for PVC are more diverse than those

Table 10

1968 MARKETS FOR LARGE VOLUME THERMOPLASTICS
(Percent of total consumption of each resin)

	LDPE	HDPE	PP	PVC	PS
Molding					
Injection	13	21	41	3	50
Blow	2	42	--		
Powder and other	--	--	--	5	--
Extrusion					
Film and sheet	44	4	7	6	
Wire and cable	9	3	--	12	
Other extruded coating	11	2	--		14
Fibers and filaments	--	--	35	14	
Pipe and conduit	--	2	--		
Other	--	--	--		
Calendering					
Flooring	--	--	--	10	--
Other	--	--	--	18	--
Coating					
Paper and textile	--	--	--	5	11
Flooring	--	--	--	2	--
Plastisols	--	--	--	5	--
Other (incl. adhesives)	--	--	--	4	2
Other domestic uses (incl. foam)	9	17	7	11	20
Export	12	9	10	5	3
TOTAL	100	100	100	100	100

for any other resin; in addition to its major uses in extrusions (particularly wire and cable), PVC dominates the phonograph record molding market and the calendered products market, and shares (with PS) the substantial markets in coatings and adhesives.

PLASTICS INDUSTRY SURVEY

Most of the required data on waste amounts and dispositions were previously unpublished, and were available only through extensive personal contacts with appropriate industry sources.

A. Survey Procedure

The procedure ultimately employed for conducting the industry survey was to a large extent governed by a directive of the U.S. Bureau of the Budget, issued shortly after this study was initiated. That directive (in accordance with the provisions of the Federal Reports Act) required that each Federal Contractor obtain formal Bureau clearance before undertaking any extensive program of visits to industrial firms to collect data. The survey clearance procedure required the prior submission to BOB of a detailed sample questionnaire, covering the information that was intended to be solicited from industry.

The questionnaire for this study was submitted in three parts: Part I was directed to major polymer producers, Part II to plastics processors and fabricators, and Part III to manufacturers of waste disposal equipment. It solicited the following general types of information:

- The sources, amounts, and forms of polymer waste generated
- Disposal methods in use, investigated, or planned
- Satisfactory and unsatisfactory aspects of current disposal methods
- Disposal equipment capabilities and costs.

The Bureau of the Budget, in turn, permitted selected industry representatives to preview the original draft of the questionnaire, with the request that they comment on its format and content, for the dual purpose of enhancing the ultimate value of the study and of minimizing the burden on respondents. This phase of the clearance procedure took approximately seven months, during which time the project was placed on standby status except for routine literature review.

The final approved version of the survey questionnaire (reproduced in Appendix A) was virtually identical with the original draft, except for relatively minor changes to incorporate the comments of the industry reviewers. Even this version was employed primarily as a guide, every effort being made to provide respondents with maximum flexibility in reporting useful information about polymer waste, without requiring any unnecessary disclosures of proprietary company data.

The plan originally called for a survey of approximately 30 industrial organizations, roughly equally divided among the three broad industry categories represented by the three-part questionnaire. For each selected company, permission was also requested to supplement the questionnaire with a brief personal visit, to facilitate the clarification of details relating to the surveyed data.

In general, most industry contacts were very cooperative, once a management decision had been reached regarding participation in the survey. Only one of the eight polymer producers originally approached declined to participate in any way. The other seven each permitted a visit either to a typical plant or to its central engineering headquarters, and all but one of those visited ultimately furnished the data requested in the questionnaire. However, several companies, each producing more than one resin type, did choose to restrict their data responses to one type

only, and this had the undesirable effect of changing the originally planned balance of resin types covered in the survey. (The terms of our clearance from the Bureau of the Budget specified that our contacts with resin producers be limited to the originally selected eight.)

In the case of processors and fabricators, about half of those contacted cited a firm policy against any plant visits, but even most of these agreed to respond to the questionnaire. Many companies volunteered to provide separate detailed responses for each of several plants or divisions. Table 11 shows the distribution of the 47 plants for which responses were ultimately received, according to principal operation, and Table 12 the distribution according to principal application. Comparison of Tables 11 and 12 with the market data of Table 10 indicates that the survey of processors and fabricators represents a broad cross section of the thermoplastics industry, with the exception of that part devoted to fibers and filaments, calendered products, and most coating applications.

Table 11

DISTRIBUTION OF SURVEYED PROCESSORS AND FABRICATORS BY PRINCIPAL OPERATION

	Reporting Plants
Compounding	2
Rotation molding	2
Blow molding	15
Injection molding	4
Extrusion	16
Thermoforming	8
Total	47

Table 12

DISTRIBUTION OF SURVEYED PROCESSORS
AND FABRICATORS BY PRINCIPAL APPLICATION

	Reporting Plants
Molding compounds	2
Film and sheet	13
Foamed articles	3
Flexible packaging	5
Rigid containers	17
Pipe, conduit, wire and cable	3
Molded toys, housewares, etc.	4
Total	47

For the third part of the survey (dealing with manufacturers of waste disposal equipment), the formal survey questionnaire proved to be generally impractical to use. On the basis of our literature review and our discussions with resin producers and plastics fabricators, we judged that incinerator manufacturers comprised the principal group of interest in relation to plastics disposal capability. A selected group of 18 of these were contacted by letter and telephone, and those who professed to offer the required capability to handle plastic wastes were invited to submit all available technical and cost data. Personal visits were made to only four incinerator manufacturers.

B. Survey Data on Polymer Solid Wastes

In compliance with the provisions of the Federal Reports Act, production and processing data provided by individual companies cannot be identified by company. Furthermore, such data must be treated in strict confidence, and must be used only for the express purposes of this study. Therefore, the numerical results of the industry survey are reported here only in the form of industry-wide aggregates, averages, and ranges.

1. Polymer Types Produced or Processed. From the seven primary resin producers that were surveyed, responses were obtained for four plants producing both high-density and low-density PE, two plants producing only high-density PE, and one plant producing PVC. (Data for additional plants, making PS and PVC, were solicited but not received.) The reported data are thus highly weighted toward the PE segment of the thermoplastic resin producers.

Although all major thermoplastics were included in the survey of processors and fabricators, the resulting data are likewise heavily weighted toward the PO segment of the industry. In large part, this results from the emphasis given to the various molding and extrusion processes (the main users of PO resins), rather than to calendering and coating applications (which favor use of PVC and PS resins). For the 47 plants for which responses were obtained, the total waste tonnage had approximately the following distribution by polymer type:

Polyethylene	59%
Polypropylene	19
Polystyrene	4
Polyvinyl chloride	18
Total	100%

2. Industry Sources of Polymer Solid Wastes. Table 13 shows the reported average distribution of polymer solid wastes among various plant sources. This tabulation (and all others from the survey) represents only true waste and excludes any sold scrap or reclaimed polymer. Waste fractions contaminated with large amounts of inorganics (such as filter aid) have been adjusted to a polymer-only basis. The data obtained did not permit any breakdown by individual resin type.

3. Amounts of Polymer Solid Waste Generated by Industry. The seven primary resin plants for which data were provided ranged in estimated production capacity from 125 to 550 million pounds per year, and their reported range of polymer solid waste generation rates was from 0.85 to 22.5 tons per day per plant. Relative to total polymer production, the reported waste generation rates ranged from 0.5 to 4.0 percent. (Where not reported directly, total polymer production was estimated at 90 percent of capacity, in accordance with trade forecasts for 1969.)

The aggregate polymer waste generation rate for all seven reporting resin production plants was 35.5 million pounds per year, corresponding to 1.75 percent of their estimated aggregate polymer production rate of 2.04 billion pounds per year. On this basis, the average resin producer generated 7.7 tons of polymer waste per day per plant in 1969. (See Table 3, Summary.)

As explained previously, the above data are strongly weighted toward the PE segment of the industry. However, the 1.75 percent figure may be applied with reasonable confidence to all PO resins (6.2 billion pounds total U.S. production forecast in 1969), to give an estimate of 108 million pounds per year of PO waste generated by resin producers.

Table 13

REPORTED SOURCES OF POLYMER WASTES

	Average Percent from Each Source	
	Primary Resin Producers	Processors and Fabricators
Off-grade product	26	65
Emergency dumps of reactor	8	--
Normal spillage, contaminated	22	19
Cleanout and maintenance	16	16
Removal from effluent gas or liquid	20	--
Other (low melting wax, etc.)	8	--
	100	100

The very limited portion of the survey data representing producers of other thermoplastic resins suggests that their polymer solid waste generation represents a considerably smaller percentage of production, probably between 0.4 and 0.8 percent. If a value of 0.6 percent waste is applied to the rest of the thermoplastic resin production (estimated to be 7.6 billion pounds per year in 1969), the estimated current waste generation rate is 45 million pounds per year from producers of thermoplastic resins other than PO.

On the basis of these separate estimates for PO and other resin types, the total estimated 1969 generation of all thermoplastic polymer solid wastes by U.S. resin producers is 153 million pounds per year, equivalent to 1.1 percent of total estimated 1969 thermoplastics production of 13.8 billion pounds per year. (See Table 3, Summary.)

Our survey of plastics processors and fabricators resulted in data representing 47 plants (16 operating divisions of 11 companies), corresponding to a total estimated polymer processing rate of 781 million pounds per year (roughly 6 percent of the 13.8 billion pounds per year forecast as the 1969 national production rate of all thermoplastics). These 47 plants reported an aggregate polymer solid waste generation rate of 17 million pounds per year, equivalent to 2.2 percent of their total polymer processing rate, and also equivalent to an average of about 0.6 tons of polymer solid waste per day per plant. (See Table 3, Summary.)

In contrast to the case of resin producers, the available data on processors and fabricators do not support a conclusion that the amount of waste is markedly correlated with the type of thermoplastic resin in any given application. Hence, the 2.2 percent figure may be considered applicable to all resins. On the other hand, the amount of reported waste varies considerably as a function of the application (as shown in Table 4, Summary). Such critical applications as electrical wire

and cable insulation have a very high reject rate (whose plastic content is not reclaimable) whereas, at the other extreme, such noncritical items as molded toys, housewares, and decorative articles may have virtually zero nonreclaimable scrap.

4. Prospects for Change in Waste Amounts. All resin producers agreed that fluctuations in the price of plastic scrap could have a major effect on drawing the line between scrap and waste. What was considered "scrap" three or four years ago is "waste" now, because of the much higher selectivity of the scrap market. Aside from the above factor of salability, the seven reporting companies had quite varied estimates of future prospects for change. Only one predicted a substantial increase in waste generation; this was attributed to the currently planned improvement in the removal of polymer solids from the aqueous plant effluent. Respondents from four plants predicted no significant change in either the generation or the reclaiming of waste polymer; on the other hand, each of these four readily conceded that from 30 to 40 percent of present waste might be reclaimed, but not economically at present. A 50 percent reduction in waste was anticipated at one plant within a year, primarily by a current program of improvements in reclaiming, rather than by reduction in generation. At the final plant, contemplated process changes were expected to lead to 25 to 30 percent less waste generation in 1 to 2 years.

Of the 47 reporting plants of fabricators and processors, 25 predicted no significant changes in either the generation or the reclaiming of present wastes; 20 predicted minor reductions of up to 30 percent; 2 predicted major reductions of from 75 to 80 percent. All of those 22 respondents anticipating reductions expected them to be attributable to improved salvage and reclamation techniques, rather than to lower waste generation rates.

5. Physical Form of Wastes. Table 14 shows the reported physical forms of the polymer solid wastes generated by the industry prior to any processing to facilitate disposal. The "Other" category in Table 14 was not always well defined by respondents, but generally included (in the case of resin producers) such forms as fluff, crumb, waxes, and thin skins, and (in the case of processors and fabricators) such forms as large reject bottles, clothesline, cable insulation, and tubing.

Very few instances of changes in physical form made specifically to facilitate disposal of wastes were reported. Melting of waxes prior to their incineration is practiced by one of the resin producers surveyed. Rejected large rigid containers are generally reground by fabricators to reduce their bulk, and some waste film and sheet is compressed and baled to facilitate handling.

6. Present Disposal Practice. Four of the seven surveyed resin plants were reported to resort almost exclusively to open dumping on company lands; two plants were reported to utilize sanitary landfill on company land; one plant was reported to employ mainly incineration. (An eighth plant, which was visited but did not submit a completed questionnaire, is known to incinerate most of its polymer solid wastes.)

Of the 47 processing and fabricating plants surveyed, the vast majority (32) were reported to use sanitary landfill as the principal waste disposal technique. Only one respondent admitted to burning in an open dump, and only three reported open dumping with no burning. The remaining eleven respondents professed to have no knowledge of or control over the ultimate disposal technique used by the private contractors that they employed to haul away their waste. None of the surveyed processors and fabricators reported incineration as the principal disposal technique, although six plants were reported to use it occasionally as a backup method.

Table 14

REPORTED PHYSICAL FORMS
OF POLYMER WASTES

	Average Percent of Each Form	
	Primary Resin Producers	Processors and Fabricators
Pellets	18	14
Chopped or shredded	0	3
Dust or powder	23	3
Random large (>100 lb)	10	28
Random small (<100 lb)	14	17
Other	35	35
	100	100

In contrast to the resin producers, none of the processors and fabricators specifically claimed the use of company land for dumping or landfill. (This information was not explicitly requested on the questionnaire; all those respondents who volunteered it indicated that they relied on public agencies or private contractors for their land disposal operations, and that each of the land disposal sites handled many kinds of municipal and industrial wastes.

The above data on reported present disposal practices are summarized in Table 15. The survey team did not have the opportunity to determine by personal inspection if the reported instances of sanitary landfill actually adhered to the accepted engineering definition of that term (particularly in regard to the use of daily earth cover). In fact, it is quite likely that many of those respondents who claimed the use of sanitary landfill really meant open dumping of nonputrescible (and hence "sanitary") material. It is also likely that the eleven instances of "unknown" disposal practice, shown in Table 15, should properly be assigned to "land disposal," without specification as to type.

7. Special Disposal Problems. Resin producers reported few special problems associated with disposal of specific wastes. Resins that contain inorganic filler or contaminant sometimes cause ash fusion problems on incineration and are therefore landfilled instead. Incineration of PVC wastes is generally avoided because of liberation of corrosive, toxic gases.

The main special problems reported by processors and fabricators are those associated with the excessive bulk of fabricated shapes.

Table 15

REPORTED PRESENT
POLYMER DISPOSAL PRACTICES

	Number of Reporting Plants	
	Primary Resin Producers	Processors and Fabricators
Open dumping	4	4
Sanitary landfill	2*	32*
Incineration	1	0
Unknown	--	11
	7	

* Not verified by inspection. (See text.)

8. Reported Waste Management Costs. The costs reported by respondents in this survey covered an exceedingly wide range and obviously represented a wide variation in company cost accounting practices. Moreover, respondents were generally unwilling to disclose the breakdown of their total reported costs into components of initial waste collection, in-plant handling, out-of-plant transportation, direct disposal operating costs, and equipment amortization. It was thus not possible to arrive at any meaningful comparison of direct disposal costs for various disposal techniques. The reported costs must generally be regarded as total waste management costs.

For the responding resin producers, the reported polymer solid waste management costs ranged from $3 to $60 per ton of waste, with the weighted mean for all seven plants being $26 per ton. The weighted mean cost represents the ratio of $470,000 (the total dollars reported to be spent annually by all seven plants) to 18,000 tons (the total reported annual amount of polymer solid waste from all seven plants).

The weighted mean polymer solid waste management cost for the 47 plants of the responding processors and fabricators was $23.50 per ton, representing a reported aggregate annual expenditure of $200,000 and an aggregate annual polymer solid waste generation of 8,500 tons. Only two respondents reported a cost of less than $7 per ton, and only three reported a cost of more than $30 per ton. (Those five extreme cases actually exerted a negligible influence on the computed mean cost.)

If these two weighted mean costs ($26.00 per ton, and $23.50 per ton) are assumed to represent the average experience of all U.S. resin producers and of all U.S. processors and fabricators, respectively, then the U.S. plastics industry spent about $5.6 million in 1969 to manage its 360 million pounds of polymer solid waste (see Table 3, Summary), for an overall average unit cost of about $24.30 per ton.

None of the industry respondents reported any financial credits from power or steam generation or any other activity related to polymer solid waste disposal. It should again be emphasized, however, that this survey obtained data only for true waste, excluding any sold, reclaimed, or recycled polymer scrap. (A special situation does exist in the wire and cable industry because of the high salvage value of the copper in scrap cable. However, it would be highly misleading to classify the vital operation of copper reclamation as merely a means for obtaining a credit from disposal of plastic wastes.)

9. Industry Comments and Recommendations. With respect to the six resin plants that are presently using land disposal, two respondents expressed no concern about continued land availability in the foreseeable future, whereas four recognized this as a problem, ranging from acute and immediate in the northeast United States, to relatively minor and deferred at least 5 to 10 years in several Gulf Coast locations. At two of the plants that are presently open dumping, there will shortly be a change to sanitary landfill, primarily to improve the appearance of the grounds. For the one plant that is now incinerating, there is complete satisfaction with the technique, except for possible cost reductions not yet achieved.

There was a virtually unaminous desire for development of improved reclamation methods and uses for low grade, contaminated plastics. Next in priority was the desire for improved incinerators, particularly those that could accept random mixtures of physical forms without expersive handling and segregation. Two respondents explicitly recommended the development of efficient, economical, centralized disposal facilities, each capable of processing all types of wastes from many plants in a given area.

Plastics processors and fabricators were not as directly involved with ultimate disposal as were the primary resin producers. Hence, they were generally less concerned about optimum long-term solutions. Those reportedly dumping or landfilling were content to continue present practices until forced to change when land becomes unavailable or too expensive. All were anxious to reduce waste generation and to improve salvage and reclamation techniques. Fabricators generally expressed a desire for more advanced size-reduction and bulk-reduction methods for fabricated shapes.

EVALUATION OF ALTERNATIVE TREATMENT AND DISPOSAL TECHNIQUES

The orderly classification of waste disposal methods is necessarily somewhat arbitrary. One might say that any disposal method must involve at least one of the following objectives: removal from view, destruction, or utilization. A useful distinction among methods can thus be made, except that some methods may involve more than one objective. (For example, sanitary landfill of municipal or other biodegradable wastes may involve all three objectives, if it simultaneously results in land reclamation.) In the following discussion, such ambiguous cases are arbitrarily categorized according to their single most obvious short-term objective, in the specific context of polymer solid wastes.

Such terms as "pipelining" and "rail haul" (sometimes loosely referred to in the literature as waste disposal methods) are of course merely methods of transport, which must be used in conjunction with some true disposal method. There is no intent here to minimize the importance that efficient, economical transport bears to the success of any disposal technique; it is merely pointed out that this report discusses transport methods, where appropriate, as a subcategory of the associated ultimate disposal method.

A. Methods Based Primarily on Removal from View

The three methods discussed under this category include open dumping on land, ocean dumping, and sanitary landfill.

1. Open Dumping on Land. All too often open dumping provides less than adequate concealment or removal from view; nevertheless, that is its ostensible rationale for nondegradable wastes, because dumps are typically located in out-of-the-way (and hence at least temporarily out-of-sight) places.

Open dumping of municipal wastes has been roundly condemned (and justly so) not only for its pollution of air, water, and landscape, but particularly for its furnishing of a harbor for insects, rodents, and other disease vectors. On the other hand, polymer wastes that are not mixed with putrescible wastes are essentially nonpolluting, and hence it would seem that the main objection to their disposal by open dumping is one of esthetics.

An important qualification must, however, be attached to the description of dumped polymer wastes as "essentially nonpolluting;" namely, it is that they are prone to being set afire, in which event they become exceedingly air polluting. Such fires, once started, are notoriously difficult to extinguish and are invariably characterized by incomplete combustion, acrid odors, and thick black smoke.

This fire hazard is perhaps the main reason why open dumping must be regarded as an unacceptable disposal method for polymer wastes--unacceptable even as a short-term technique, and even for those companies having adequate land of their own, well concealed from public view. As a long term proposition, there is no question that open dumping will be ruled out automatically because of the ultimate unavailability of suitable sites within economic hauling distances.

2. Ocean Dumping. Disposal at sea usually takes one of two forms:

a. Bulk dumping in comparatively shallow water from hopper barges

b. Deep sea dumping in sealed containers.

The second technique is very expensive and has no applicability to polymer wastes. The first technique is potentially economical and practical for disposal of relatively dense, inert materials. However, many polymer solid wastes do not qualify for this method, because they tend to float to the surface of the water rather than to settle permanently to the bottom. (The normal ranges of density for unfilled polymers are: 0.91 to 0.965 for PE or PP, 1.04 to 1.10 for PS, and 1.16 to 1.35 for PVC.)

3. Sanitary Landfill. There is a common misconception by many of the lay public (and even by many technically sophisticated people) that the term "sanitary landfill" is merely a euphemistic label for an open dump. According to the most recent authoritative standards,[7] "A sanitary landfill is defined as an engineering method of disposing of solid waste on land by spreading the waste in thin layers, compacting the waste to the smallest practical volume, and covering the waste with earth each day in a manner which prevents environmental pollution."

This report will not attempt to go into detail about all the engineering factors--site selection and preparation, area and volume requirements, cover material, equipment requirements, operating procedures and options, maintenance, and safety--entering into a successful sanitary landfill operation. These factors have already been well covered in the literature. The principal advantages and disadvantages of sanitary landfill are summarized in Table 16. It should be evident that several of the disadvantages listed in Table 16 apply mainly to municipal wastes containing a relatively high proportion of food waste or putrescible material. If a sanitary landfill is devoted exclusively to plastic wastes (or to these plus other nonbiodegradable materials), then those disadvantages relating to pollution of ground water and evolution of gas will not apply.

Table 16

SUMMARY OF SANITARY LANDFILL CONSIDERATIONS

ADVANTAGES	DISADVANTAGES
1. Where land is available, the sanitary landfill is usually the most economical method of solid waste disposal.	1. In highly populated areas, suitable land may not be available within economical hauling distance.
2. The initial investment is low compared to that of other disposal methods.	2. If proper sanitary landfill standards are not adhered to, the operation may result in an open dump.
3. A sanitary landfill is a complete or final disposal method as compared to incineration and composting where residue, quenching water, unusable materials, etc., remain and require further disposal.	3. Location of sanitary landfills in residential areas can result in extreme public opposition.
4. A sanitary landfill can be put into operation within a short period of time.	4. A completed landfill will settle and require periodic maintenance.
5. A sanitary landfill can receive all types of solid wastes, eliminating the necessity of separate collections.	5. Special design and construction must be utilized for buildings constructed on completed landfill because of the settlement factor.
6. A sanitary landfill is flexible; increased quantities of solid wastes can be disposed of with little additional personnel and equipment.	6. Methane, an explosive gas, and the other gases produced from the decomposition of the wastes may become a hazard or nuisance problem and interfere with the use of the completed landfill.
7. Submarginal land may be reclaimed for use as parking lots, playgrounds, golf course, airports, etc.	

Source: "Sanitary Landfill Facts," Public Health Service Publication 1792.

Plastics in certain physical forms may introduce special problems in landfills, because they are difficult to compact efficiently with ordinary equipment (tractors, draglines, or steel-wheeled compactors). Plastic films in particular tend to become entangled in the treads, wheels, and radiators of spreading and compacting equipment. Film manufacturers generally compress and bale waste film prior to its disposal, to avoid such difficulties.

Initial sanitary landfill investment costs normally include those for land, planning and design, construction, and equipment. The major part of initial investment is usually for land and equipment, and most of these costs can often be recovered through development of the land.[6] If investment funds are limited, leasing of either the land or the equipment, or both, should be considered.

Operating costs for sanitary landfills (including leasing or amortization costs, but excluding the costs of initial waste collection and hauling) are commonly reported to range from $0.50 to $5 per ton of waste. The upper end of this wide range of costs reflects primarily the low efficiency of the smaller operations, which are normally run on a part-time basis. Large, efficient landfills handling 50,000 tons or more of municipal waste per year may be expected to operate at about $1 per ton.[6] Hauling costs can often add from $4 to $6 per ton, or more, to the total cost. Collection costs, usually the most labor-intensive item, can also be the dominant cost item, adding as much as $25 per ton to total costs for extremely bulky wastes, such as some polymer wastes.

B. Methods Based Primarily on Destruction

This category of solid waste treatment methods emphasizes primarily the reassimilation of the wastes (or their breakdown products) by nature, rather than their conversion to a useful form. It includes biodegradation and weathering, chemical oxidation, and incineration.

1. Biodegradation and Weathering (including Composting). It is well known, based on considerable past research, that most unplasticized synthetic polymers are very resistant to attack by bacteria, fungi, or marine organisms. For this reason, plastics have gained a generally justifiable reputation as being nonbiodegradable. Similarly, although plastics are not completely immune to the ultraviolet component of sunlight, this form of attack is extremely slow and is restricted to a thin surface layer. Thus, plastics are too resistant to weathering to permit the efficient disposal of plastic wastes by this method.

In regard to macrobiological resistance, rodents and various boring insects have been known to chew their way through many kinds of plastics blocking their way to food. Rats have even been alleged to chew through plastic pipe or electrical insulation merely to keep their teeth in condition. However, all of these types of attack are quite obviously unsuitable for plastic waste disposal. Termites may represent a unique type of macrobiological attack on plastics. Published information is scanty, but it appears that termite attack is quite widespread and that a number of different termite genera are capable of attacking many kinds of plastics, including PE and PVC. Termites cannot utilize synthetic plastics as food, but there is evidence that they do use small bits of plastics to build their covered runways. It is thus likely that termites can play a role in the ultimate disintegration of plastics in sanitary landfills, but it is doubtful that the rate of destruction by termites could be high enough to increase landfill capacity significantly over the short term.

Composting (defined as the aerobic, thermophilic bioconversion of organic wastes to a relatively inert, sterile residue) has found limited economic success in Europe as a means of producing a salable soil conditioner for flower growing and other luxury agriculture. In this country,

commercial compost plants have had a dismal economic history, because of their inability to dispose of the large quantities of compost at a favorable price, within reasonable hauling distance.

Because of the nonbiodegradability of synthetic plastics, composting has little or no effect on them. Composting cannot therefore be considered to represent a disposal method for plastics. However, for the case of plastics mixed with municipal refuse, composting does offer the option of a significant total volume reduction prior to burial, as a means of prolonging the life of a given sanitary landfill site.

In spite of these potential technical advantages, however, such a combination of composting-plus-landfilling has thus far not gained acceptance in this country, presumably because the added cost of the composting step is still considered unjustifiable. In the future, as landfill sites become less available, the importance of preliminary volume reduction techniques will increase.

2. Chemical Oxidation. All polymers, natural or synthetic, will eventually degrade in an oxygen atmosphere at elevated temperatures. Many of the commercially important thermoplastics undergo autocatalytic oxidation at temperatures below 200 C. Most of the past research on this subject has been devoted to the inhibition of oxidative degradation of polymers, rather than to its utilization for polymer waste disposal.

Chemical processing is generally more expensive than other solid waste treatment methods. Its consideration is usually justified in the hope of converting the waste to a valuable product. However, in the case of plastic wastes, a mild chemical treatment might prove to be economically justifiable even if it served only to accelerate the subsequent weathering or biodegradability of the wastes in normal landfill operation.

Recently, IIT Research Institute has been engaged in a laboratory study (Contract No. PH-86-67-274, sponsored by the Bureau of Solid Waste Management) of the feasibility of the disposal of PE plastic waste by chemical means, including oxidation of air, oxygen, ozone, chlorine, nitrogen tetroxide, nitric acid, sodium hypochlorite, organic peroxides, and metallic nitrates, chlorates, and peroxides. That study has shown that chemical treatment of plastic can modify the mechanical, thermal, and biochemical properties of the material so that ultimate disposal would be facilitated. The most attractive approach appeared to be one involving thermal oxidative degradation and concomitant nitration.

It is known that paraffin wax can be catalytically oxidized with air, at moderate temperature and atmospheric pressure, to a mixture of monobasic acids. Presumably, a similar technique should also be applicable to PE. Moreover, it is likely that continued oxidation of the initially produced monobasic acids could convert them to dibasic acids in high yield. The main uncertainty about such a process is probably the technical and economic feasibility of the separation of the relatively complex product mixture.

3. Incineration. To a sizable fraction of the public, the burning of solid wastes represents a pollution source rather than a pollution control method. This attitude is conditioned by their memory of smoky, odorous, burning dumps or municipal incinerators. Most solid waste disposal experts today would agree that modern incineration technology, incorporating effective pollution control techniques, can make incineration one of the most acceptable disposal methods. The main products of properly conducted incineration--carbon dioxide, water vapor, and an inert solid residue--can be completely assimilated by nature without upsetting any ecological balance. (Of course, certain types of wastes may liberate unusually large amounts of toxic or corrosive combustion products, making incineration less practical for disposal of such materials.)

a. Special Design Characteristics for Plastics Incineration. Plastics (particularly thermoplastics) have gained a certain degree of notoriety with regard to the special problems they may introduce during their incineration. They do not ignite or burn readily in many types of conventional incinerators; they melt and clog grates; they deposit as smoldering molten puddles which may burn erratically or even explosively; they have very high heating values (15,000 to 20,000 Btu per pound) and the resulting high flame temperatures require special furnace designs; and chlorinated plastics such as PVC liberate toxic and corrosive HCl as a combustion product.

The consensus of polymer producers and of incinerator manufacturers is that all the above problems can be overcome by proper design and operation. The most critical design features pertinent to plastics incineration appear to be the following:

1. To avoid clogging of grates, thermoplastic wastes are best burned in a furnace having a smooth, solid hearth. (Various fixed hearth, rotary hearth, and rotary kiln designs satisfy this criterion and have proven successful.)

2. The combustion chamber should be preheated to the ignition point before any polymer wastes are charged, and the supply of overfire air must be controlled to avoid building up high concentrations of flammable vapors.

3. For smokeless operation, the combustion temperature must be at least 1800 F (preferably at least 2000 F) and the flammable vapors evolved from the polymer wastes must be retained for a sufficient time at this high temperature (often accomplished in a second-stage chamber), to permit combustion to go to completion. The requisite high temperature generally demands use of special furnace refractories.

4. If large quantities of polymer waste are involved, it is almost mandatory (for technical and economic reasons) that the incinerator be operated 24 hours per day and 6 or 7 days per week.

5. For best results, polymer wastes should not be combined with other plant trash for incineration. If they can be burned alone, control of combustion can be made good enough to eliminate the need for any abatement of odors, fly ash, or smoke. (Exception: if PVC or other chlorinated wastes are burned in large quantities, a gas scrubber must be installed to remove the HCl.)

6. To avoid high operating and maintenance costs and eliminate costly supervision, polymer wastes should be shredded to a reasonably uniform size and fed at a constant rate to the incinerator.

7. Waste heat boilers can be incorporated into the incinerator system. However, a full-scale incinerator must be provided ahead of the boiler, so that all volatile matter has completed its combustion before the gases enter the boiler section. If the combustion products include corrosive gases, the boiler tubes must be operated at a temperature above the dew point of the gas, but below about 550 F, to minimize corrosion of the tubes. So-called "water-walled" furnaces, popular in Europe for incineration of municipal refuse, are not recommended by U.S. incinerator manufacturers for combustion of predominantly plastic wastes, because the presence of a cool wall tends to quench the flame and lead to excessive smoke.

b. Applicable Incinerator Designs Offered by Manufacturers. Over half of the more then twenty incinerator manufacturers contacted in this study conceded frankly that they did not offer any equipment suitable for incineration of high-Btu solid wastes (15,000 to 20,000 Btu lb).

Several of the others indicated that they were actively developing designs capable of handling 100 percent plastics, but their present models were limited to wastes having heating values in the range of 6500 to 8500 Btu per pound.

Large, grate-type municipal or industrial incinerators, said to be capable of handling solid waste containing at least 10 percent plastics, are reportedly offered by several companies. These incinerators are often combined with steam or power generation equipment.

Only six of the incinerator manufacturers we surveyed specifically claimed a present capability to incinerate 100 percent plastic wastes. Those six offered essentially only three basic types of incinerator design: the rotary kiln, the multichambered retort, and the open pit with overfire air jets. Quoted operating costs (including amortization of equipment, but excluding collection and hauling costs) ranged from $5 to $8 per ton of waste. Investment costs (including building and foundations, but excluding land) were quoted at from $6,000 to $12,000 per ton per day for the multichambered retort, the most commonly offered type; estimated investment costs for the rotary kiln were about $15,000 to $30,000 per ton per day, and those for the open pit incinerator were only about $1,000 to $2,000 per ton per day.

There was an unusually wide divergence of opinion among those surveyed who had either used the open pit incinerator or had observed it in use by others as to whether it could dependably achieve smoke-free combustion of polymer wastes. The consensus seemed to be that it could do so only under very carefully controlled uniform feeding conditions, not likely to be enforced in practice. A coarse wire screen over the pit provides the only protection against fly ash or burning particles, and this was almost unanimously judged to be inadequate.

A rotary kiln incinerator is used successfully on a mixture of plastic waste and plant trash by one of the major polymer producers whose facilities were visited but from which a completed questionnaire was not received. No instances were discovered of any rotary kiln incinerator being used for plastic wastes exclusively.

An incinerator of the multichamber retort type, rated at 30 tons of plastic waste per day, is in service by one of the PE producers surveyed in this study; it was originally used on a mixture of polymer waste and general plant trash, but is now used on PE waste only, to avoid problems of ash removal.

c. Novel Incinerator Designs. Current experimental work on incineration of solid wastes includes suspension burning, fluidized bed combustion, and pressurized burning.

Suspension burning, the process widely used in power boilers, consists in blowing the finely divided fuel tangentially into a cyclonic furnace chamber, so that it burns while suspended in the turbulent air stream. It is efficient in terms of attainable heat release rate per unit burner volume and requires no grate or supported fuel bed. It does, however, require that any solid waste used as fuel be finely subdivided.

Fluidized bed combustion takes place in a bed of inert granular material (sand) suspended over a perforated plate in a refractory vessel. The fluidized sand bed is initially preheated by the combustion products from a gas or oil burner. Subsequently, air is blown up through the bed to maintain its fluidized state. Solid waste introduced into the bed burns while circulating in the hot sand. Theoretically, excellent control and complete combustion result. Separation of any unburned residue from the bed material and maintenance of uniform air distribution can present serious problems.

Pressurized burning, by either of the above methods, makes possible a further reduction in burner volume by virtue of the high pressure employed. The main potential advantage of pressurized burning is that the hot pressurized flue gases can theoretically drive a gas turbine engine to generate power in excess of that required for compression.

Although each of the above techniques is potentially applicable to either 100 percent polymer solid wastes or to mixed wastes containing polymers, it is generally conceded that they are still in the development stage.

d. Published Incineration Costs. Based on the data in the Interim Report of the U.S. Public Health Service 1968 National Survey of Community Solid Waste Practices, the average capital cost of 170 municipal incinerators (including buildings, facilities, and engineering, but not land) is about $6,000 per ton per 24-hour day of design capacity. Fifteen plants reported capital costs above $11,000 per daily ton, and the highest reported cost was $30,000 per daily ton. It is probably safe to assume that the majority of the 170 plants included in that survey are old and obsolete, and do not do an adequate job of air pollution abatement. Efficient modern plants may be expected to require an initial investment on the order of $10,000 to $15,000 per daily ton of design capacity, based on municipal refuse as the incinerated material. Capital cost components and their relative importance may be grouped as follows: furnaces and appurtenances (60% to 65%); building (20% to 30%); pollution control equipment (8% to 10%); miscellaneous (7% to 13%).

The 1968 National Survey also provided data on operating costs of municipal incinerators. For those 78 of the surveyed facilities that actually weighed their incoming waste, the average operating cost was about $5 per ton, with four of the facilities reporting operating costs above $10 per ton. These costs include amortization, which normally amounts to from 20 to 30 percent of the total. As in the case of reported capital costs, it is probably safe to assume that the reported average operating cost of $5 per ton represents mainly old plants of a sophistication inadequate to comply with modern air pollution regulations. Well run, modern plants may be expected to require an operating cost on the order of $7 to $10 per ton.

It should of course be recognized that the total cost of waste disposal by incineration must include the costs of initial collection, hauling, and disposal of residue, if any. (Polymers alone produce no residue.)

These costs are very labor-intensive and may easily exceed the actual incinerator operating costs shown above. As an incinerator can usually be located closer to the source of waste than can a sanitary landfill, the hauling cost for the former is usually less.

C. Methods Based Primarily on Utilization

Virtually everyone would applaud any scheme whereby wastes could be recycled or otherwise reused. Such recycling or utilization, of course, implies economic feasibility. To qualify as an acceptable raw material, wastes must prove competitive cost-wise with "natural" materials.

Because reclamation methods involving use as a polymer are excluded from our discussion of polymer solid waste utilization methods (see Introduction, page 1), this disposal category consists primarily of those methods depending on the conversion of the wastes to nonpolymer forms or functions. The most prominent among these functions are the use of the wastes for their fuel value (to generate steam or power) and their use as chemical raw materials (e.g., for a pyrolysis process).

1. Centralized Treatment and Disposal, with Options of Power and Steam Generation. About a dozen large plants in Germany, most of them built since 1964, are burning municipal refuse and generating power. Two older plants are operating in Switzerland, one in Holland, and a new plant in England. A plant to make steam is being built in Canada and two are being built in Japan.

These water-wall incinerator plants cost more than the refractory-chamber incinerators with inefficient air pollution control devices, and American municipalities have avoided them simply because of this additional cost. The steam generating plants also require a higher caliber

of operating personnel, normally one or more graduate engineers for supervision. However, now that the U.S. public is reassessing the value of clean air relative to fuel economy, the incentive for power-generating refuse plants should be much greater.

The concept of centralized treatment and disposal of all kinds of industrial wastes is already beginning to catch on in the United States. Prior to 1968, no such plants were operating on this continent. Three facilities are planned to be onstream in 1970, and at least 20 others are in various stages of design.[9]

The pioneer plant of this kind is the one at Sarnia, Ontario, Canada (owned by Goodfellow Enterprises, Ltd.), which has been running since mid-1968. It handles 37 different liquid and solid wastes (produced by nine different chemical and refining plants) via five different disposal methods, while complying with all local air, ground, and water pollution regulations. The company expects to have its second facility, near Toronto, completed by the end of 1970, and is contemplating others in Canada and the United States.[9]

Rollins-Purle, Inc. has scheduled an early 1970 startup of centralized, all purpose, industrial liquid and sludge waste treatment and disposal units at Logan Township, New Jersey, and at Baton Rouge, Louisiana, and has reportedly ordered equipment for 18 additional facilities of this type. Chemtrol Pollution Services is planning a similar facility to service the Buffalo, New York area.[9]

Thus far, there are no reports that any of the above existing or planned centralized treatment and disposal plants include steam or power-generating facilities. On the other hand, steam generation is definitely an integral part of the centralized facility planned to be built in the Houston, Texas area by Consolidated Oxidation Process Enterprises, Inc. (COPE).[9] The proposed $5 million plant, designed to handle a quarter

of a billion pounds of all types of solid and liquid wastes per year, should generate for sale 100,000 pounds of low pressure steam per hour. COPE reportedly has plans for putting up similar plants in at least three other U.S. locations. However, it is still waiting for a sufficient amount of guaranteed volume before beginning construction on even the first plant. Original insistence on long-term, high-volume contracts has recently been eased in the hopes of lining up more clients.

There are many advantages in centralized treatment and disposal as a long-range solution to industrial solid waste management. An integrated facility can employ an optimum combination of several disposal systems, each designed for certain types of wastes. It is ideally suited to continous operation, to the handling of peak loads from individual customers, and to the optimum blending of various wastes to facilitate disposal. Operated on a sufficiently large scale, it should provide opportunities for economical steam and power generation too attractive to ignore.

2. Pyrolysis. Pyrolysis is defined as the chemical change brought about by the action of heat in the absence of air or oxygen. This process has been used for several hundred years to convert wood to charcoal, combustible gas, and various organic by-products (notably methanol, acetic acid, and turpentine). As chemical technology has improved over the years, pyrolysis gradually has become uncompetitive with alternative synthesis routes (based on use of petroleum or natural gas) to most of these by-products. Recently, however, interest in pyrolysis has been revived as a potential means of upgrading municipal and industrial solid wastes, including polymer wastes.

Pyrolysis of a comparatively homogeneous material (scrap auto tires) containing a high percentage of organic polymer was recently investigated by the U.S. Bureau of Mines. That study demonstrated the technical feasibility of destructive distillation as a means for obtaining potentially

valuable products from scrap tires. Typical yields from a ton of scrap were: 1,500 cubic feet of gas (mainly hydrogen, methane, and ethane, and comparable in heating value to natural gas); up to 140 gallons of liquid oils, similar in composition to conventional coal chemicals; and about 700 to 1,100 pounds of friable carbonaceous residue having a heating value of about 13,000 Btu/lb. No cost data were reported, either for carbonization or for separation of the very complex liquid fractions. (Ninety-eight compounds were identified in the light oil fraction alone.) Thus, the economic feasibility of the process as a potential source of chemicals still remains to be demonstrated.

Pyrolysis of thermoplastic polymer solid waste might be a very attractive reclamation method if it could be made to yield essentially only a single product (the monomer) in high yield. However, numerous past studies have shown that only a few polymers (e.g., polymethyl methacrylate, and poly-tetrafluoroethylene) can be made to undergo such a reversible thermal depolymerization. The vast majority of polymers, including all the high tonnage thermoplastics, exhibit complex decomposition leading to a wide spectrum of products (like that found in the tire pyrolysis study above).

The expense of separating even one or two pure compounds from such a complex mixture is likely to be too high to make the process competitive as a source of chemicals. At present, pyrolysis processes for waste reclamation may be regarded more realistically as a potential source of higher grade fuel than the original waste.

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APPENDIX A

INDUSTRY SURVEY QUESTIONNAIRE

Part I : Polymer Producers

Part II : Plastics Processors and Fabricators

Part III : Manufacturers of Waste Disposal Equipment

Budget Bureau No. 85-S68019*
Approval Expires June 30, 1969

POLYMER SOLID WASTE SURVEY

PART I: POLYMER PRODUCERS

1. How much total polymer waste does company (or individual plant) generate? (If disclosure of total polymer production must be avoided, please report waste on either a tonnage or a percentage basis, but not both.)

_____ tons of waste per day

_____ percent of polymer production represents waste polymer

2. What is the average composition of the total waste, by polymer type?

_____ % polyethylene

_____ % polypropylene

_____ % polystyrene

_____ % polyvinyl chloride

_____ % other (specify: _____)

3. On the average, what are the principal contributory sources of the total waste, and their relative magnitudes? (Please modify suggested categories if necessary or appropriate.)

_____ % transition product (between grades), not reclaimed

_____ % other off-grade product

_____ % emergency dumps of polymerization reactor

_____ % normal spillage, contaminated

_____ % cleanout or maintenance of equipment

_____ % solids removed from liquid or gaseous waste effluent

_____ % other (specify: _____)

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*This survey (under Contract No. PH 86-68-160, Department of Health, Education, and Welfare, Public Health Service) has been approved by the Bureau of the Budget, in compliance with the provisions of the Federal Reports Act. Production and processing data provided by individual companies will be treated in strict confidence, will be used only for the express purposes of this study, and will be reported only in the form of industry-wide aggregates or averages.

Form PRU-7419-I

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4. What are company (or plant) prospects for significant changes in either the generation or the salvage of polymer wastes?

_____

_____

_____

_____

5. What is the average physical form distribution of the total polymer waste (prior to any processing to change form in order to facilitate disposal)?

_____ % as pellets

_____ % as chopped or shredded

_____ % as dust or fine powder

_____ % as random large pieces ($\geq$ 100 lbs)

_____ % as random small pieces ($<$ 100 lbs)

_____ % as other (specify: _____)

6. How are total polymer wastes currently disposed of?

_____ % by incineration

_____ % by sanitary land till

_____ % by open dump burning

_____ % by open dump (no burning)

_____ % by giving away (no control over end use)

_____ % by other means (specify: _____

_____)

7. What changes in physical form of waste are currently required specifically to facilitate disposal?

_____

_____

_____

8. What are estimated total costs (including amortized equipment costs) of polymer waste disposal? (Even a rough estimate would be helpful.)

$ _____ per ton of polymer waste

Form PRU-7419-I

9. What credits, if any, are realized from polymer waste disposal (e.g., power or steam generation)?

_____

_____

10. What special problems, if any, are associated with disposal of specific polymer types?

_____

_____

_____

11. What is management judgment of both the present and the long-term acceptability of current disposal methods (i.e., in regard to cost, continuing availability of land, safety, air or water pollution, maintenance and downtime of disposal facilities, plant housekeeping, public relations, etc.)?

_____

_____

_____

_____

12. What aspect of polymer waste disposal do you regard as most urgently in need of improved or alternative techniques?

_____

_____

_____

_____

13. What is the availability of other plant wastes (e.g., still bottoms) that might be combined with polymer wastes to make some disposal methods more feasible?

_____

_____

_____

14. What other disposal methods have been, are being, or are planned to be investigated (e.g., biodegradation, pyrolysis, low-temperature oxidation, ultraviolet or gamma radiation, etc.)?

_____

_____

Form PRU-7419-I

15. What are your recommendations for future development work on disposal methods?

_____

_____

_____

_____

Form PRU-7419-1

Budget Bureau No. 85-S68019*
Approval Expires June 30, 1969

POLYMER SOLID WASTE SURVEY

PART II: PLASTICS PROCESSORS AND FABRICATORS

1. How much total polymer waste does company generate? (If disclosure of total processing rate must be avoided, please report waste on either a tonnage or a percentage basis, but not both.)

   _____ tons of waste per day

   _____ percent of virgin polymer processed becomes waste

2. What is the average composition of the total polymer waste, by polymer type?

   _____ % polyethylene

   _____ % polypropylene

   _____ % polystyrene

   _____ % polyvinyl chloride

   _____ % other (specify: _____)

3. On the average, what are the principal contributory sources of the total waste, and their relative magnitudes? (Please modify suggested categories if necessary or appropriate.)

   _____ % normal spillage, contaminated

   _____ % off-spec product, not reclaimed

   _____ % equipment cleanout or maintenance

   _____ % solids removed from liquid or gaseous waste effluent

   _____ % other (specify _____)

*This survey (under Contract No. PH 86-68-160, Department of Health, Education, and Welfare, Public Health Service) has been approved by the Bureau of the Budget, in compliance with the provisions of the Federal Reports Act. Production and processing data provided by individual companies will be treated in strict confidence, will be used only for the express purposes of this study, and will be reported only in the form of industry-wide aggregates or averages.

Form PRU-7419-II

4. What are company (or plant) prospects for significant changes in either the generation or the salvage of polymer waste?

_____

_____

5. What is the average physical form distribution of the total polymer waste (prior to any processing to change form in order to facilitate disposal)?

_____ % as pellets

_____ % as chopped or shredded

_____ % as dust or fine powder

_____ % as sheet or film

_____ % as fiber, cloth, or felt

_____ % as random shaped pieces

_____ % as other (specify: _____

_____)

6. How are total polymer wastes currently disposed of?

_____ % by incineration

_____ % by sanitary land fill

_____ % by open dump burning

_____ % by open dump (no burning)

_____ % by giving away (no control over end use)

_____ % by other means (specify: _____

_____)

7. What changes in physical form of waste are currently required specifically to facilitate disposal?

_____

_____

_____

8. What are estimated total costs (including amortized equipment costs) of polymer waste disposal? (Even a rough estimate would be helpful.)

$ _____ per ton of polymer waste

Form PRU-7419-11

9. What credits, if any, are realized from polymer waste disposal (e.g., power or steam generation)?

10. What special problems, if any, are associated with disposal of specific polymer types?

11. What is management judgment of both the present and the long-term acceptability of current disposal methods (i.e., in regard to cost, continuing availability of land, safety, air or water pollution, maintenance and downtime of disposal facilities, plant housekeeping, public relations, etc.)

12. What aspect of polymer waste disposal do you regard as most urgently in need of improved or alternative techniques?

13. What other disposal methods have been, are being, or are planned to be investigated by company?

14. What are your recommendations for future development work on disposal methods?

Form PRU-7419-II

Budget Bureau No. 85-S68019*
Approval Expires June 30, 1969

POLYMER SOLID WASTE SURVEY

PART III: MANUFACTURERS OF WASTE DISPOSAL EQUIPMENT

1. What types of disposal equipment does company make (e.g., incinerators, size reduction equipment, compaction equipment, waste segregation equipment, blending equipment, chemical reaction equipment, etc.)?

_____

_____

_____

2. What special measures or precautions (if any) are required to enable this equipment to handle polymer waste?

_____

_____

_____

_____

3. What unique or unusual capabilities does the equipment have?

_____

_____

_____

_____

4. Where is it presently used for polymer waste disposal?

_____

_____

_____

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Form PRU-7419-III

5. What is the estimated waste handling capacity?

_____ tons polymer waste per day

6. What is the total estimated cost (including amortized equipment cost) of polymer waste disposal with this equipment?

$ _____ per ton of polymer waste

7. What provisions (if any) does the equipment contain for eliminating or controlling air or water pollution?

_____

_____

_____

8. What (if any) claims are made regarding the quantitative adherence of the equipment to pollution regulations?

_____

_____

_____

9. What special provisions (if any) are included for disposal of particular wastes?

_____

_____

_____

10. What special safety provisions (if any) are made?

_____

_____

_____

11. What credits (if any) are realized from use of the equipment (e.g., power or steam generation)?

_____

_____

_____

12. What future equipment improvements (if any) are anticipated?

_____

_____

_____

Form PRU-7419-III

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